SENSEI project

Sub-**E**lectron-**N**oise **S**kipperCCD **E**xperimental **I**nstrument

Ultra low-energy threshold detectors for light DM

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December 6, 2016

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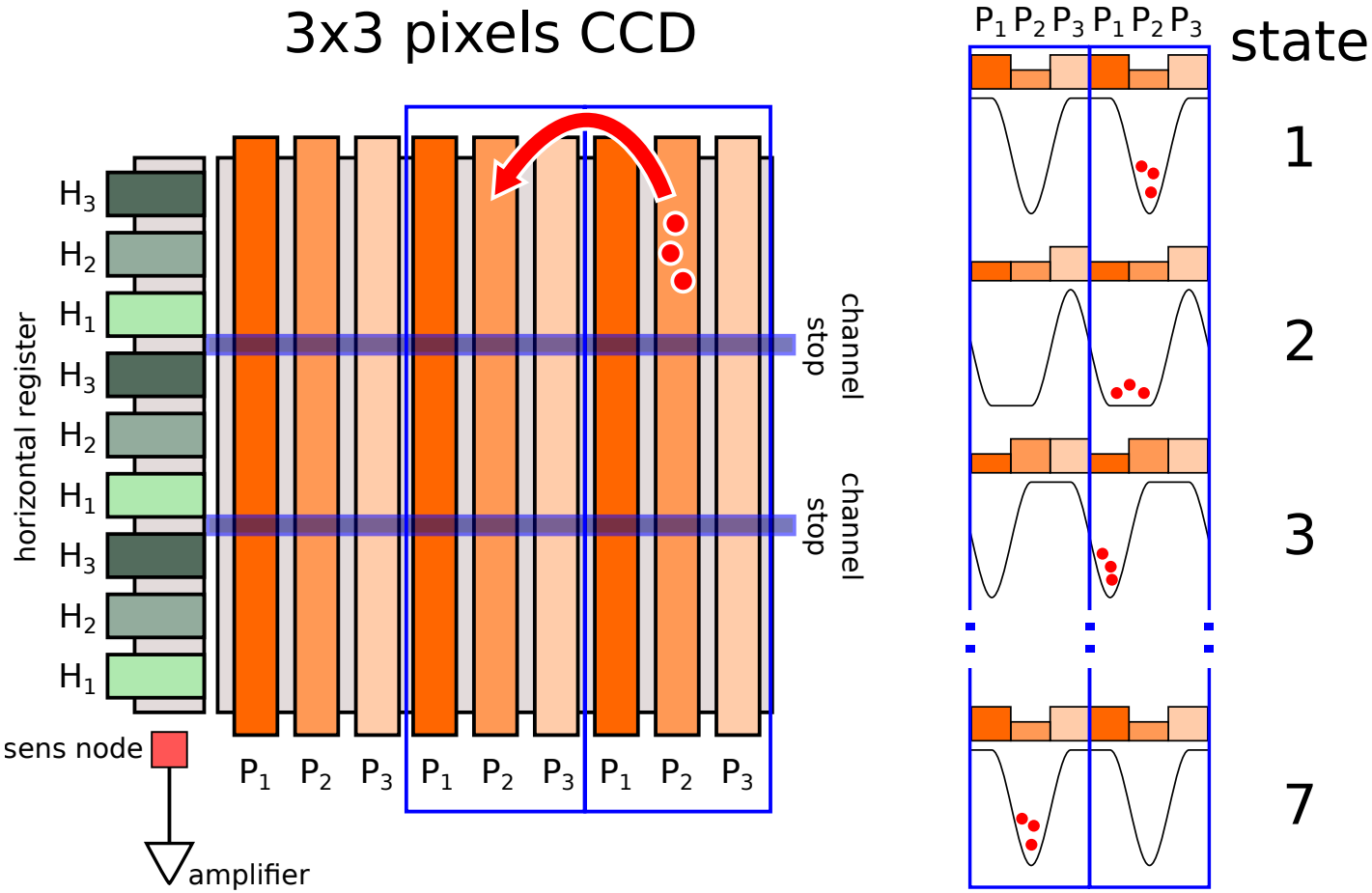
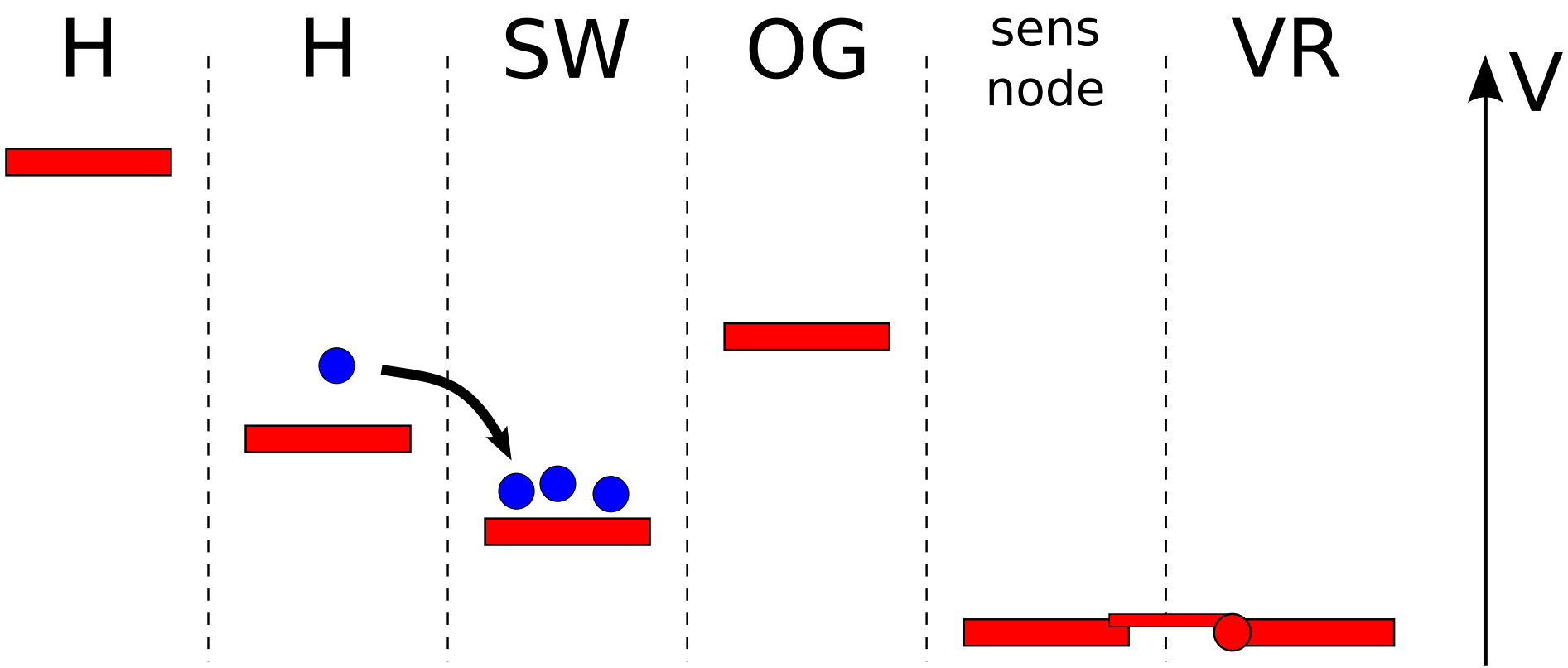
Fermilab

CCD: readout



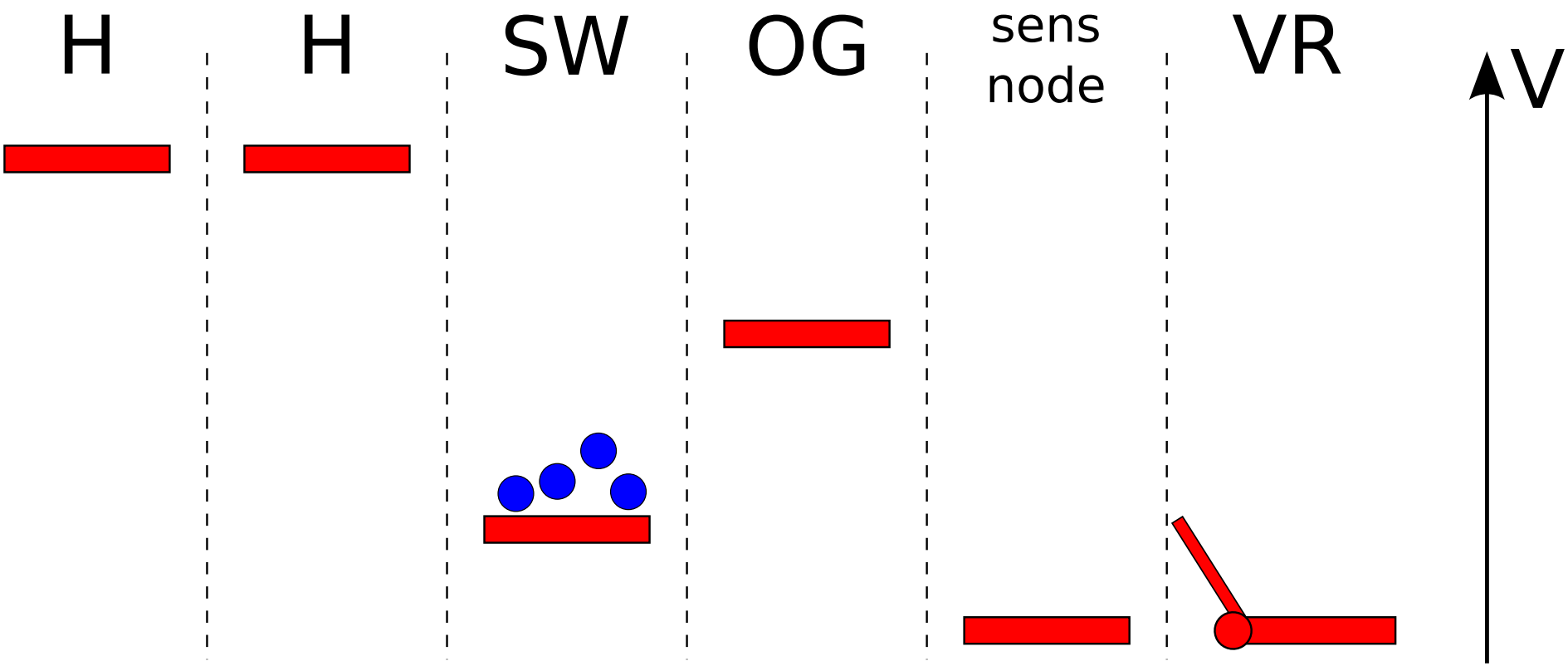
capacitance of the system is set by the SN: C=0.05pF$\rightarrow$ 3μV/e

CCD: readout



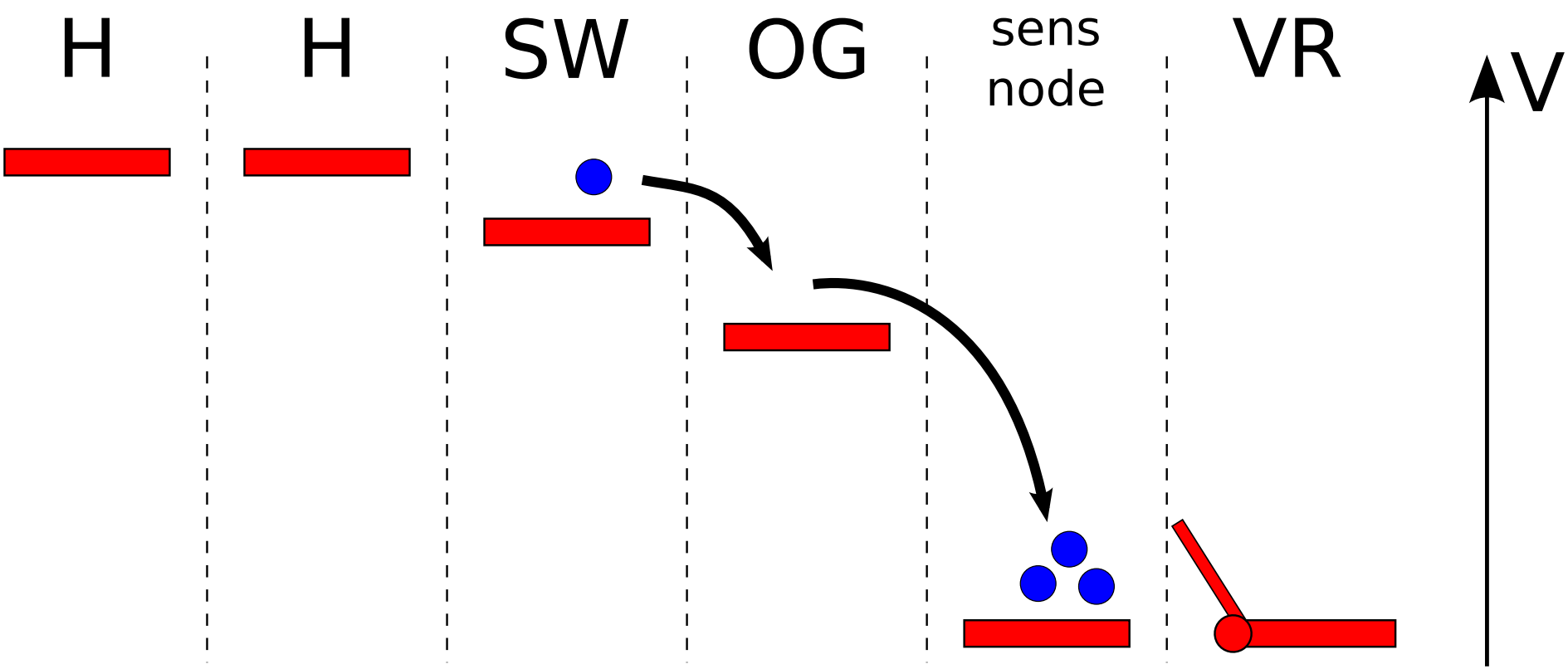
Accumulate the charge in the SW and reset the SN voltage

CCD: readout



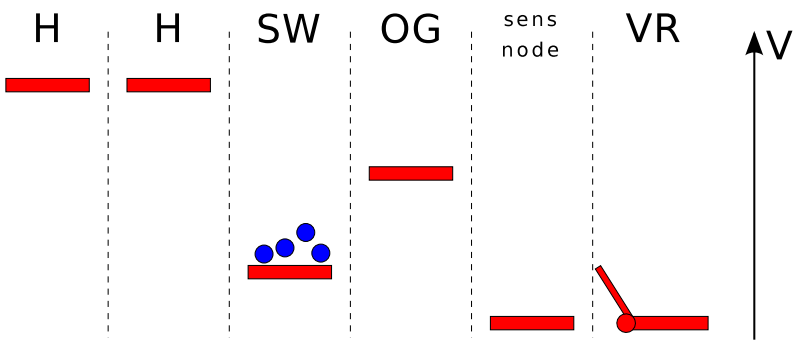
Disconnect the SN so it's floating. Measure the baseline voltage in the SN.

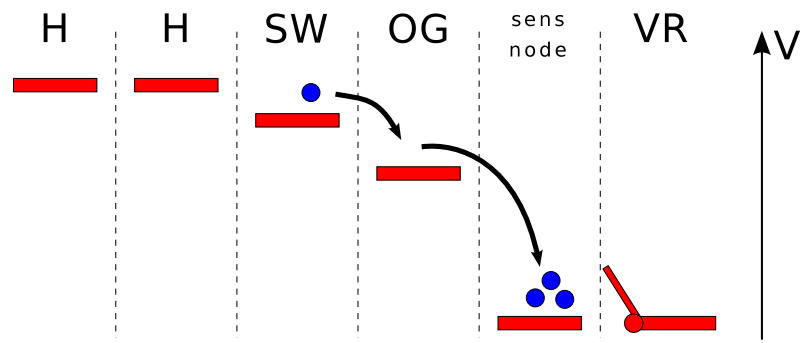
CCD: readout



Move the change to the SN and measure the shift in the voltage

CCD: readout


H
H
SW
OG
sens
node
VR
V


H
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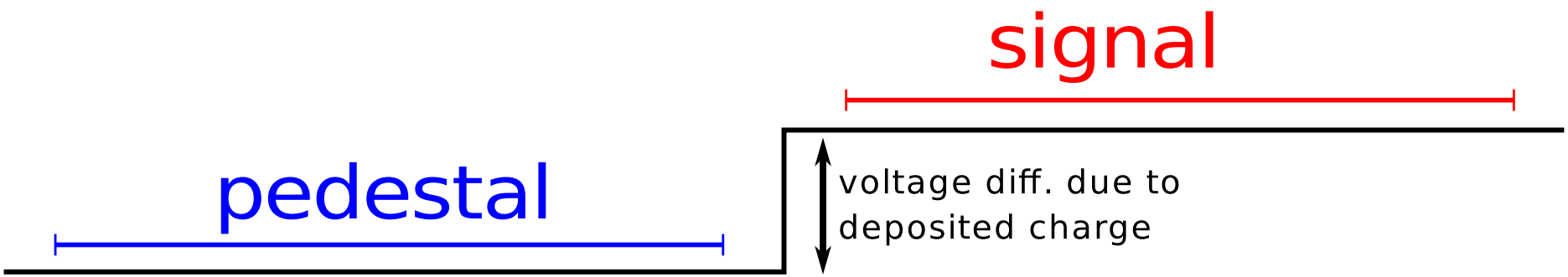
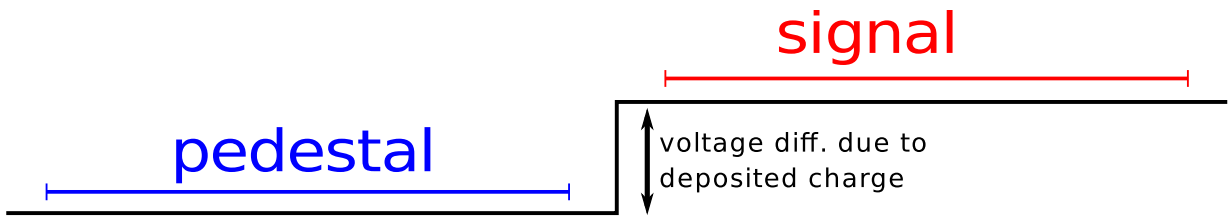
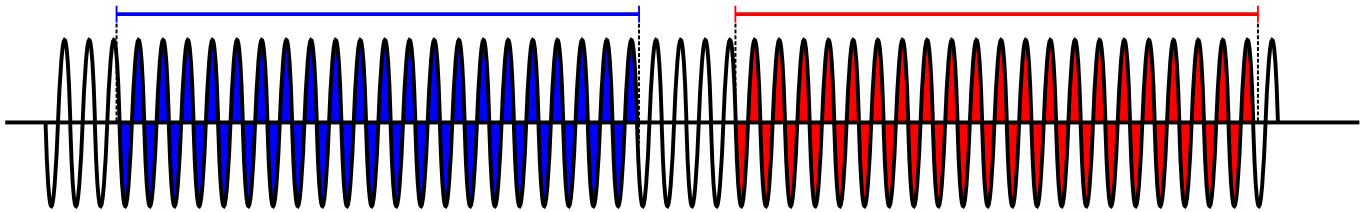

signal
pedestal
voltage diff. due to
deposited charge

CCD: readout

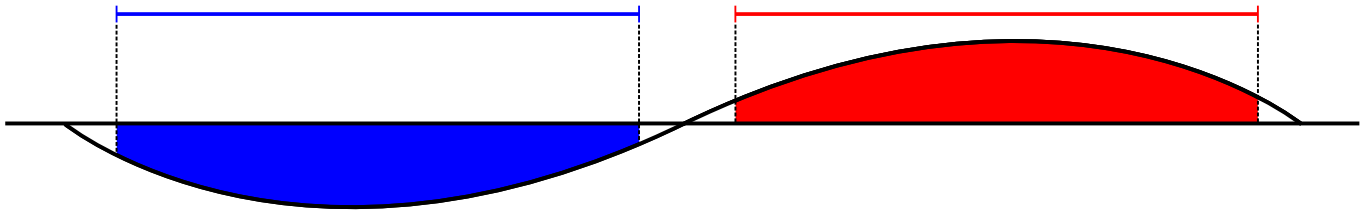
pixel charge measurement



high frequency noise

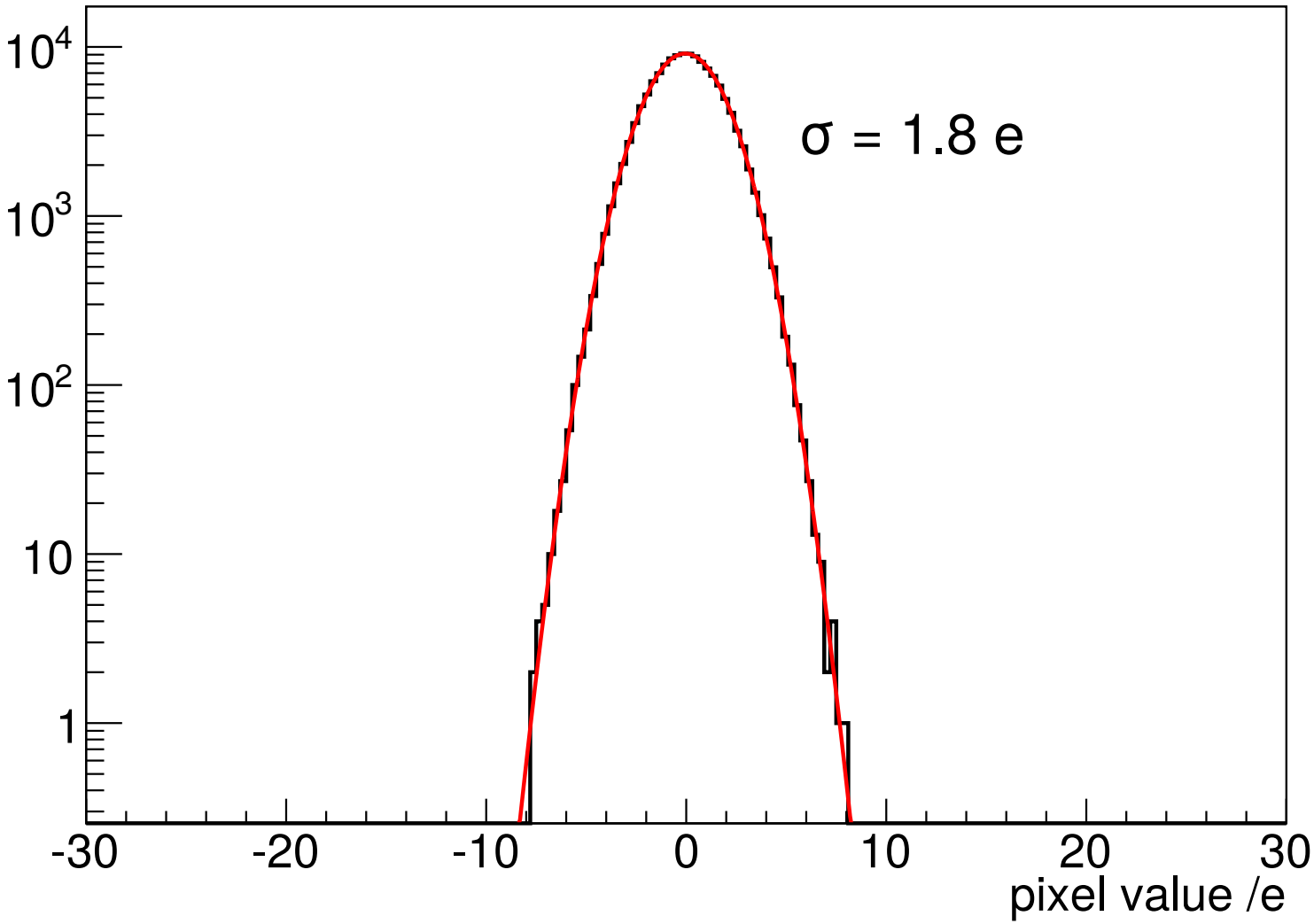


low frequency noise



excellent for removing high frequency noise but sensitive to low frequencies

Readout noise: empty pixels distribution



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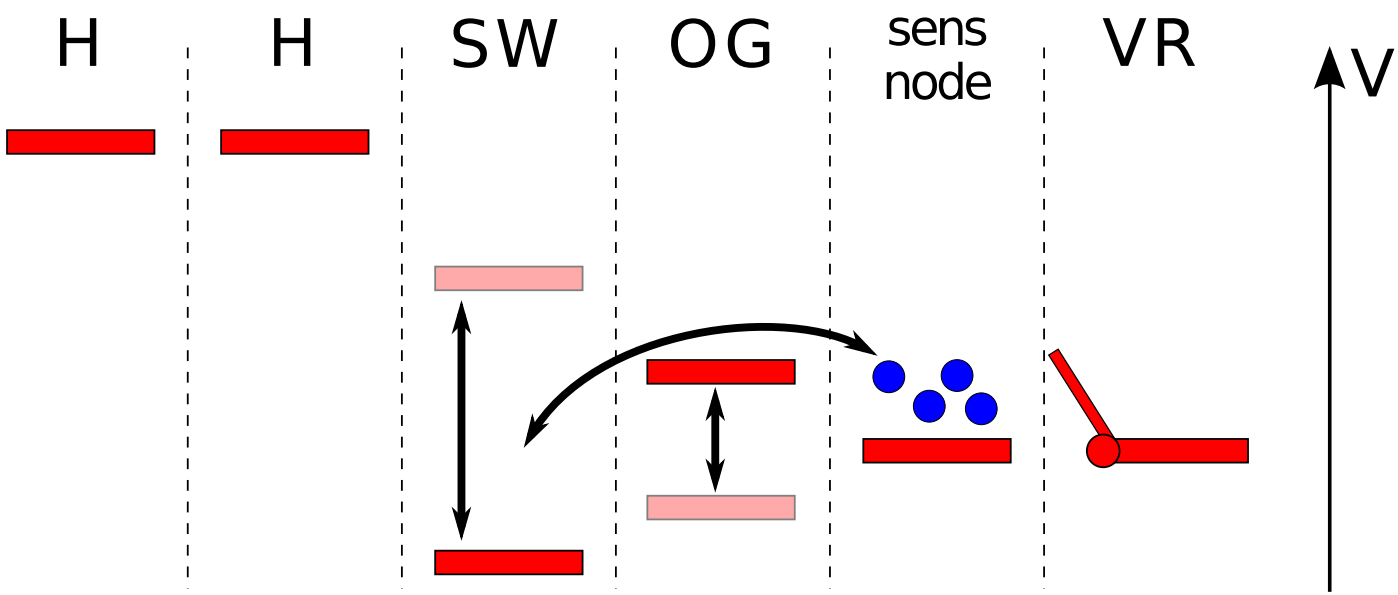
Lowering the noise: Skipper CCD

- **Main difference:** the Skipper CCD allows multiple sampling of the same pixel without corrupting the charge packet.
- The final pixel value is the average of the samples
  Pixel value $= \frac{1}{N}\Sigma_i^N$ **(pixel sample)**$_i$



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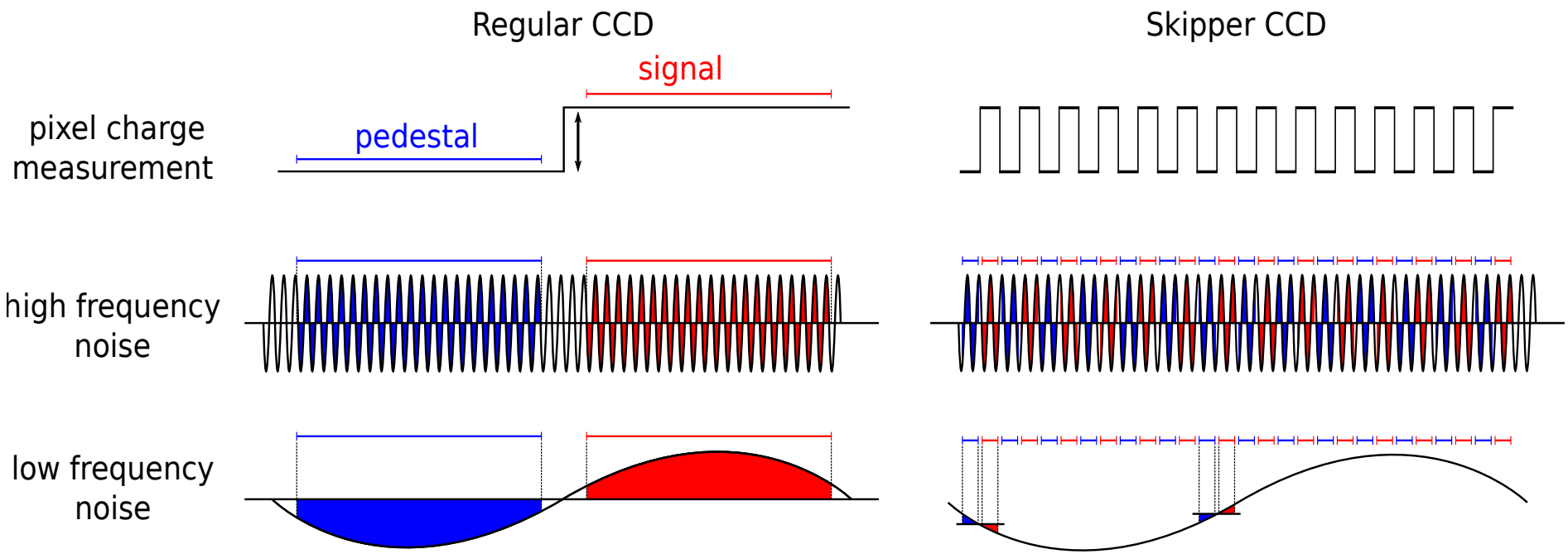
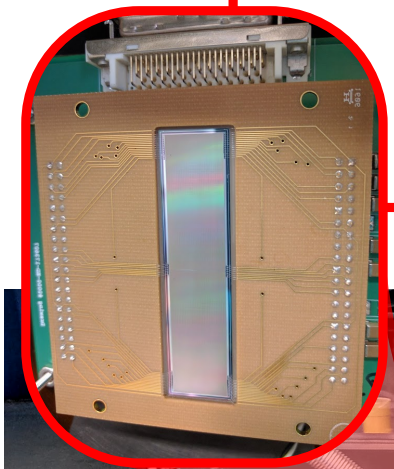


This instrument already exist: SENSEI

Skipper-CCD prototype designed
by LBL MicroSystems Lab
200 um thick
15 um pixel size
~ 4k x 1k pixels
parisitic run



Instrument build at Fermilab
Custom cold electronics
Modified Monsoon system
for read out.

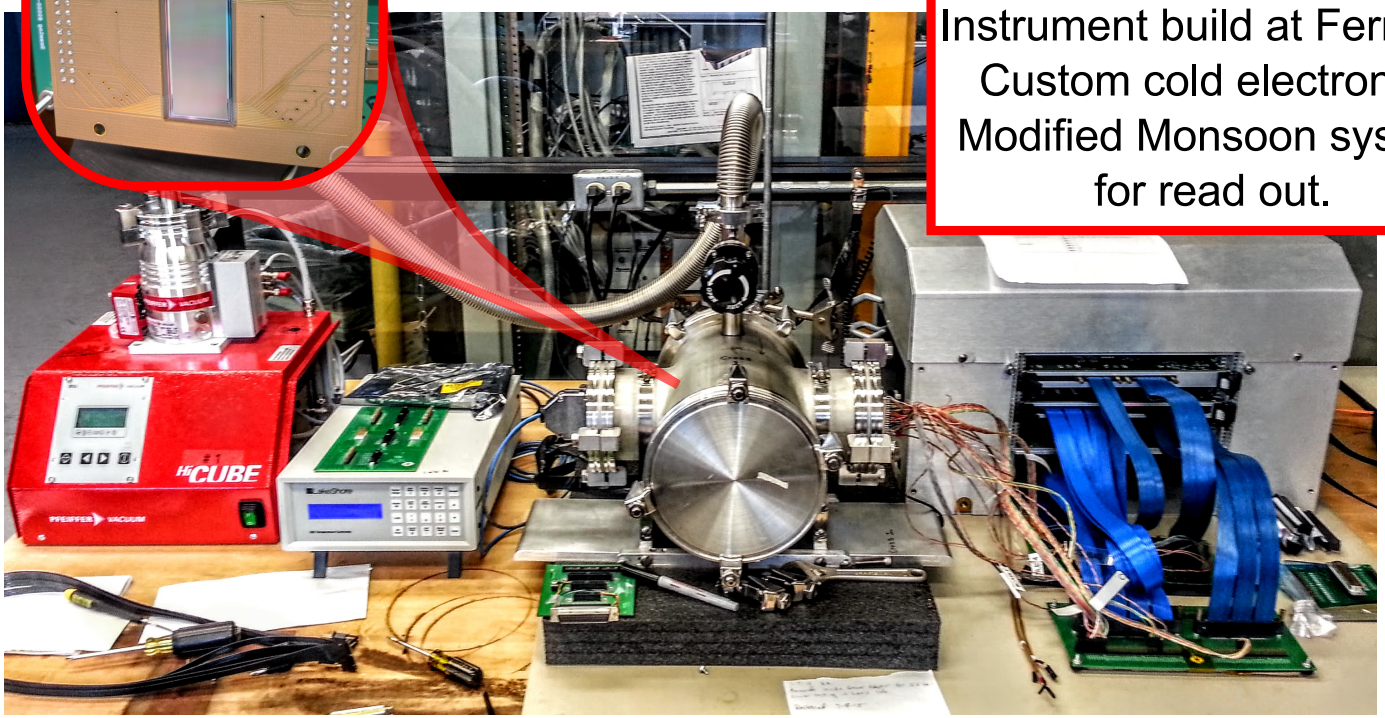


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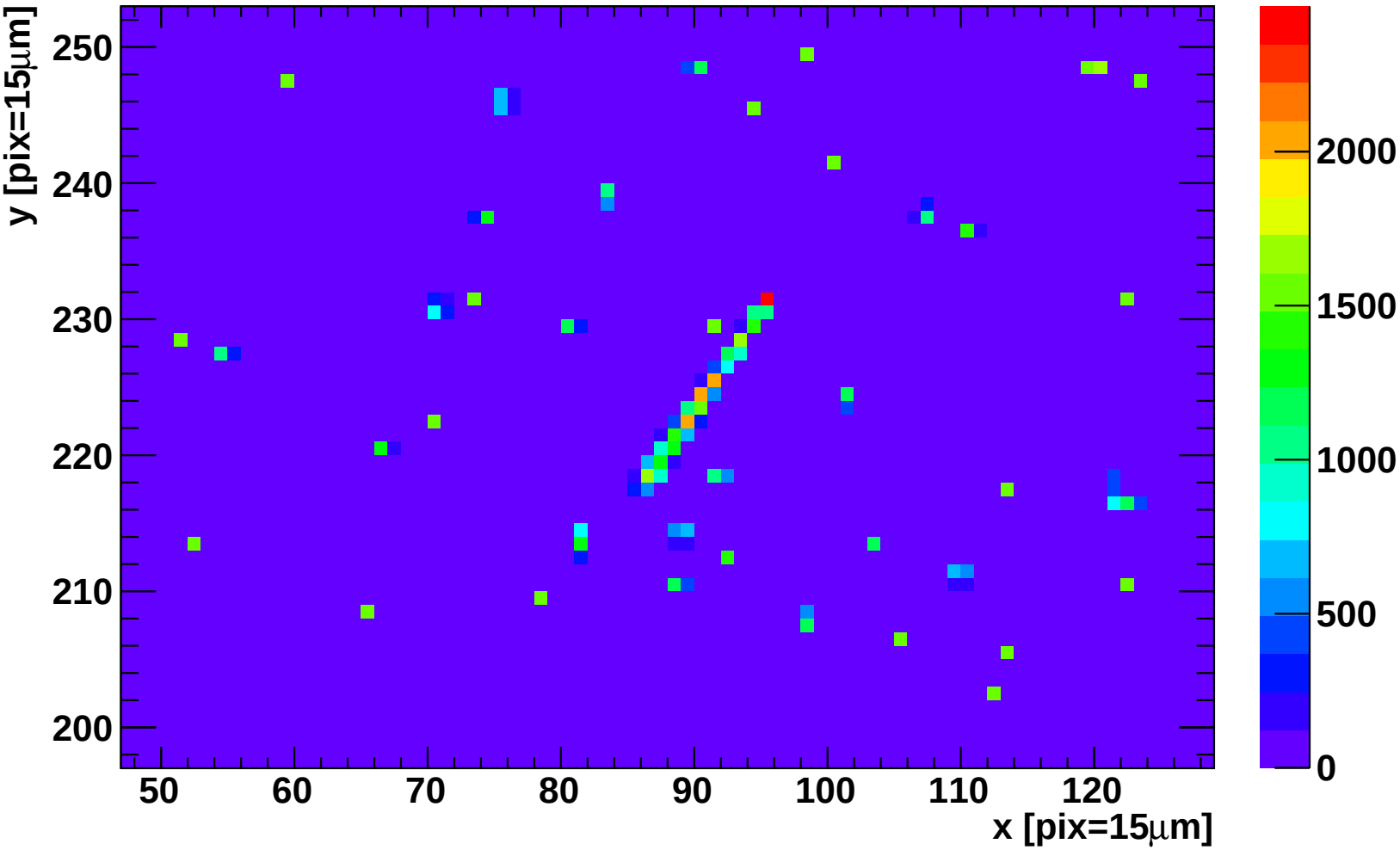
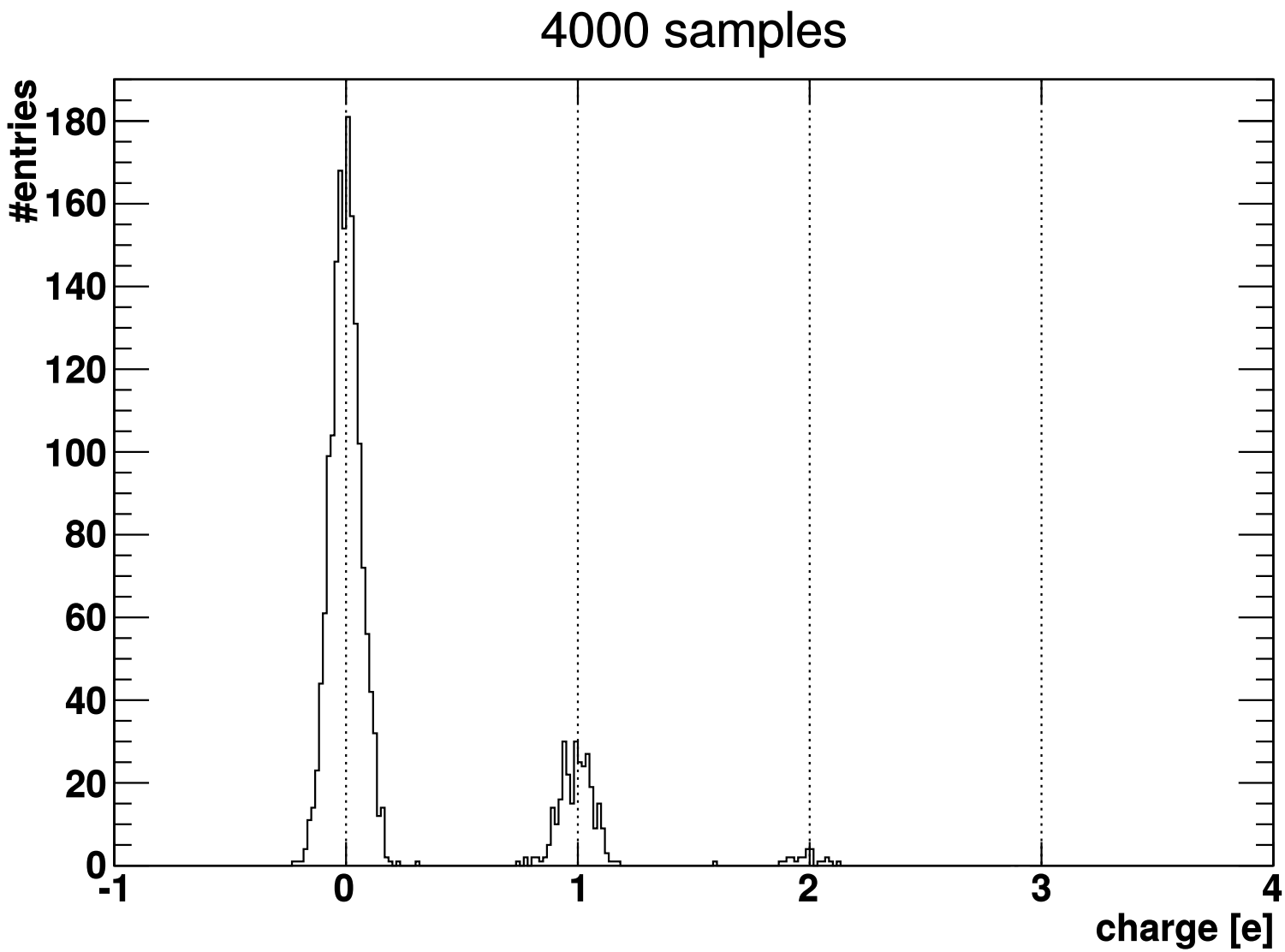
Image taken with SENSEI



Charge in pixel distribution. Counting electrons: 0, 1, 2..



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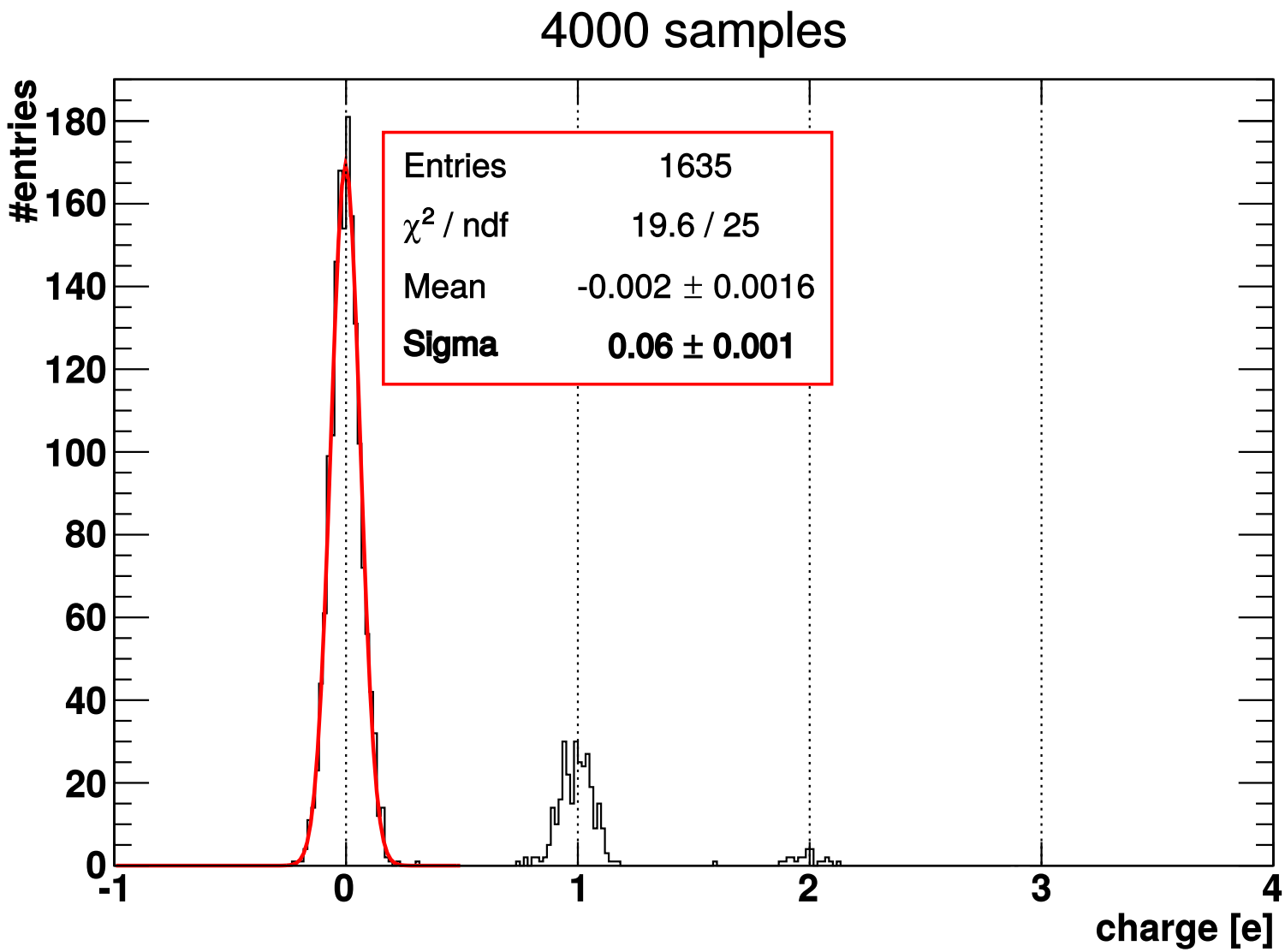
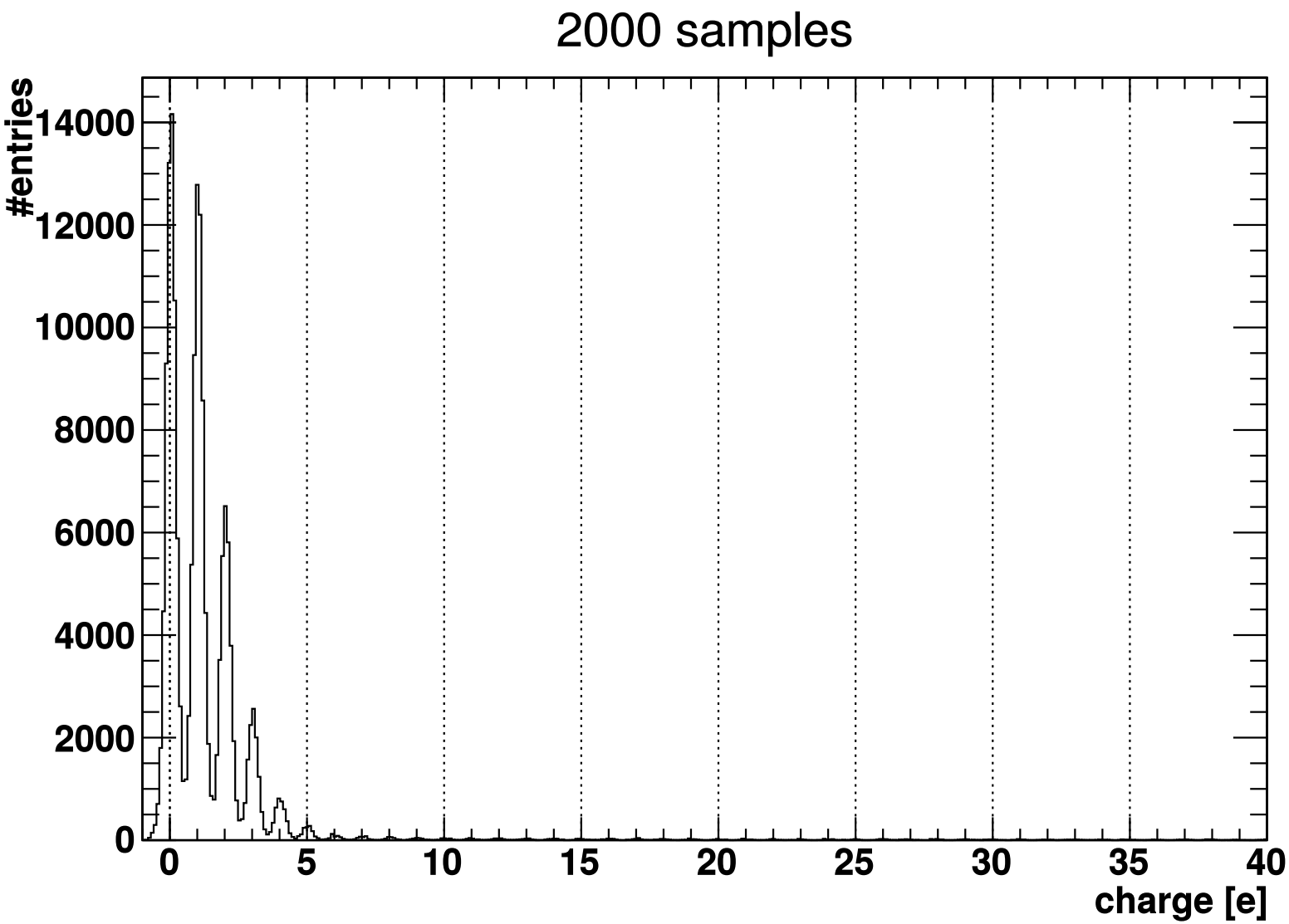


Counting electrons: ..38, 39, 40..



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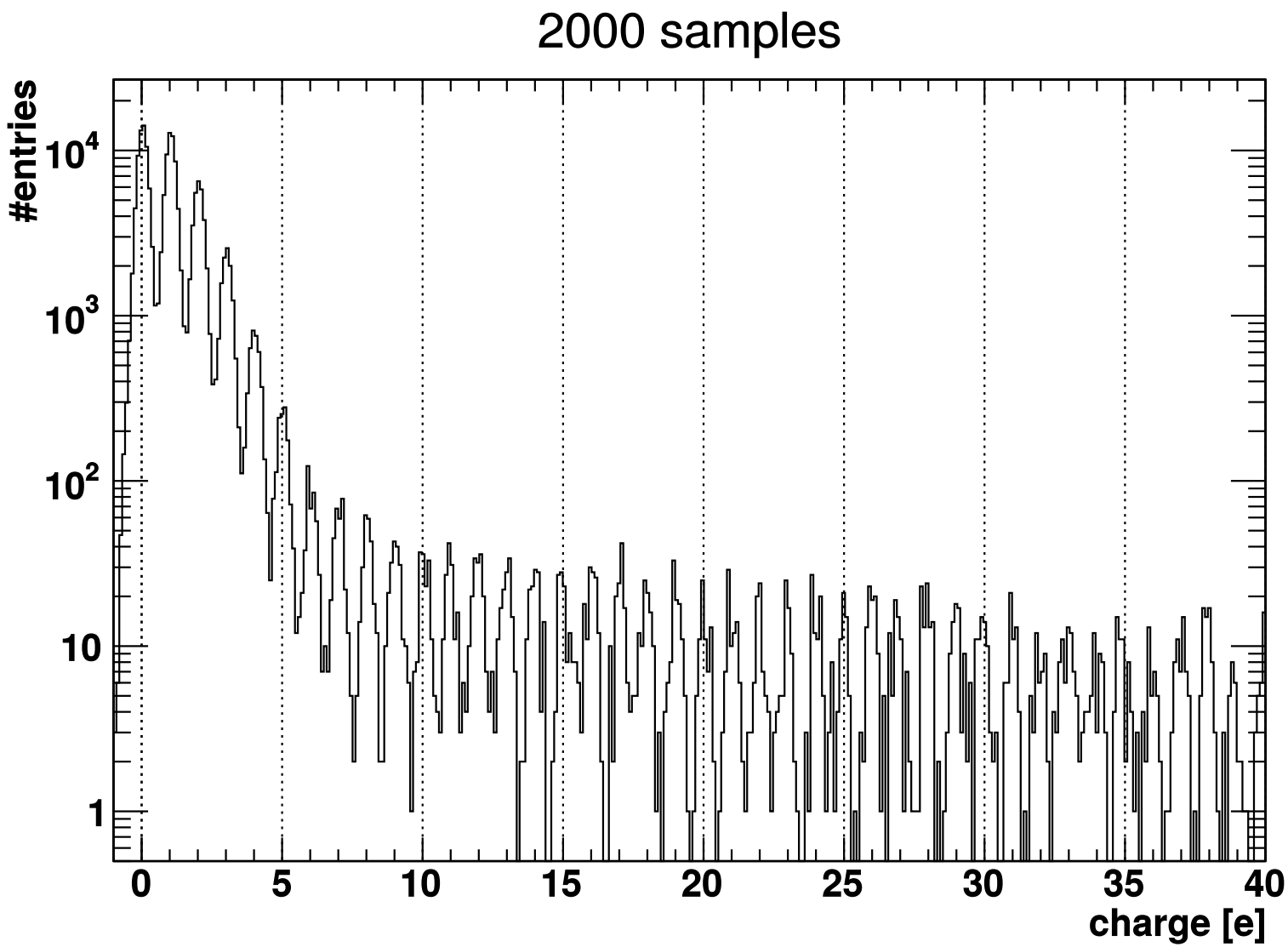
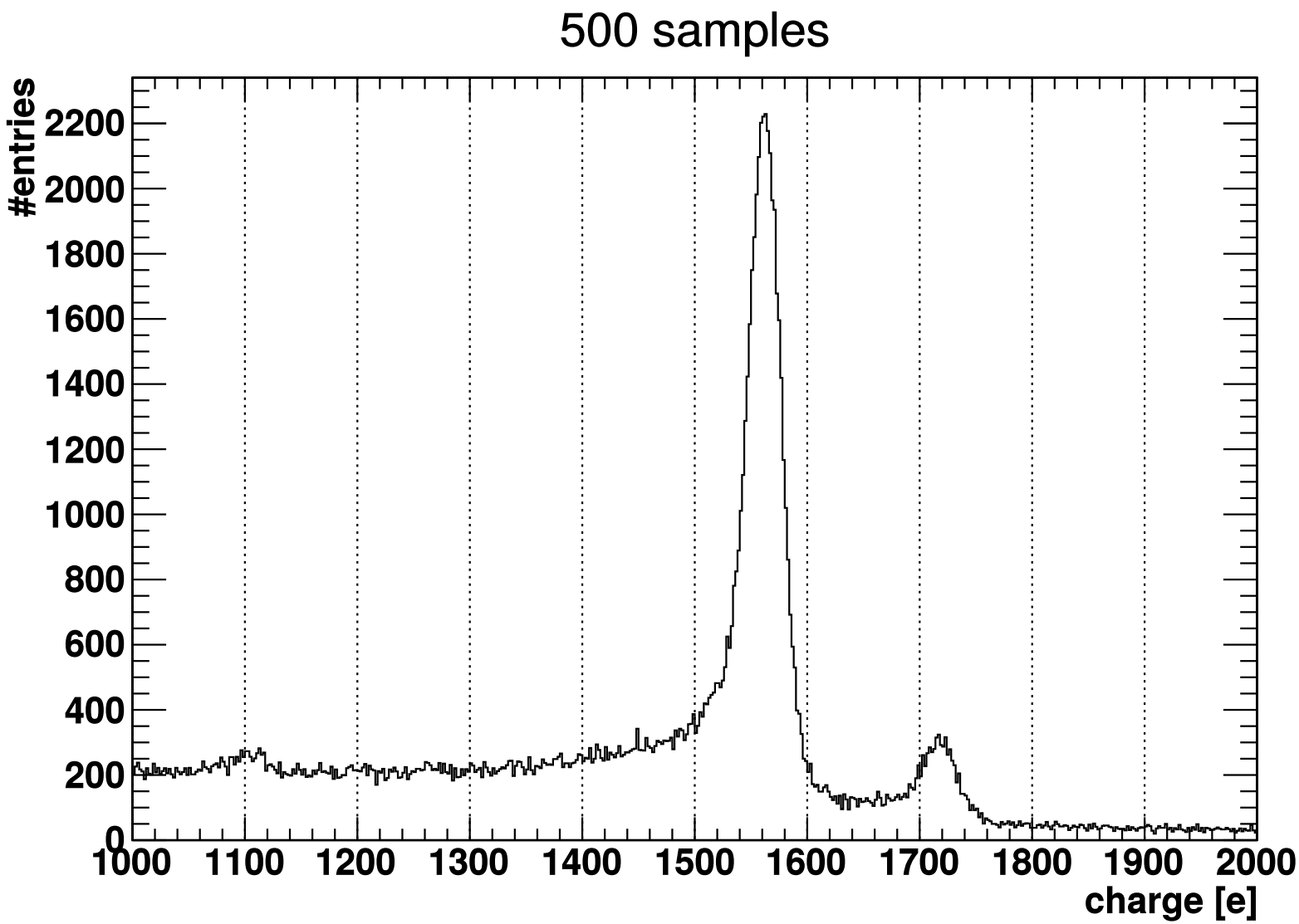


^{55}Fe X-ray source



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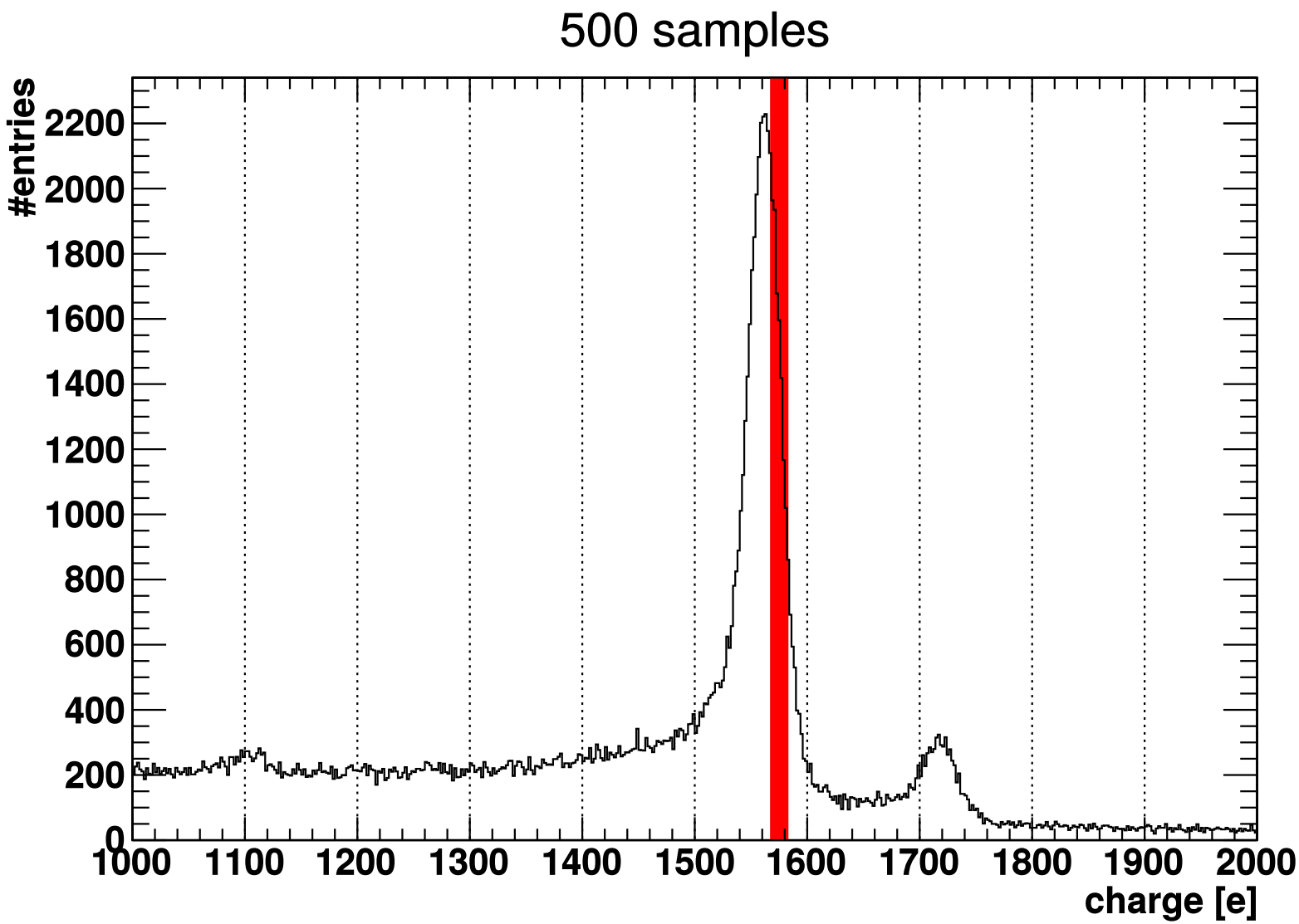
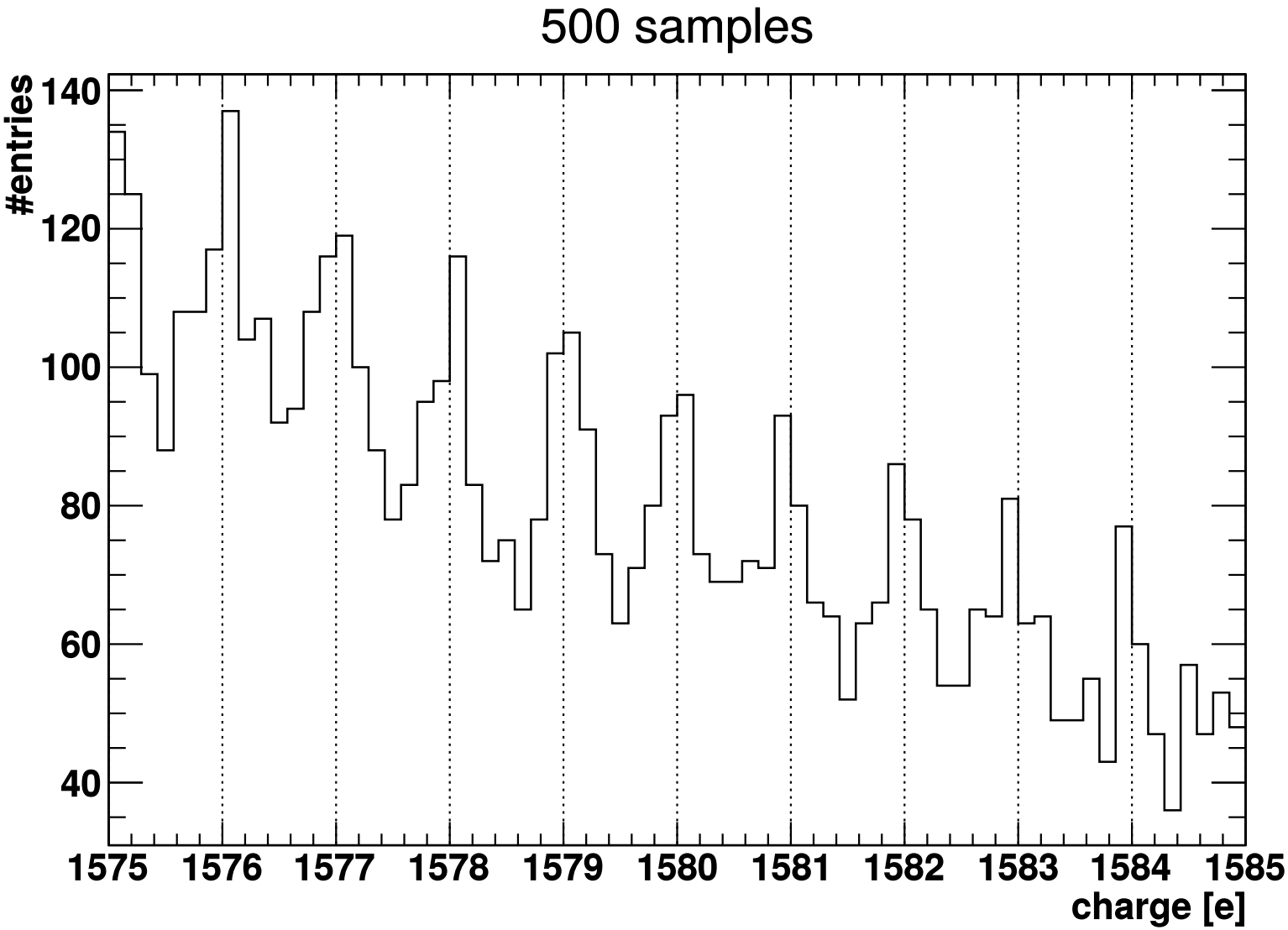
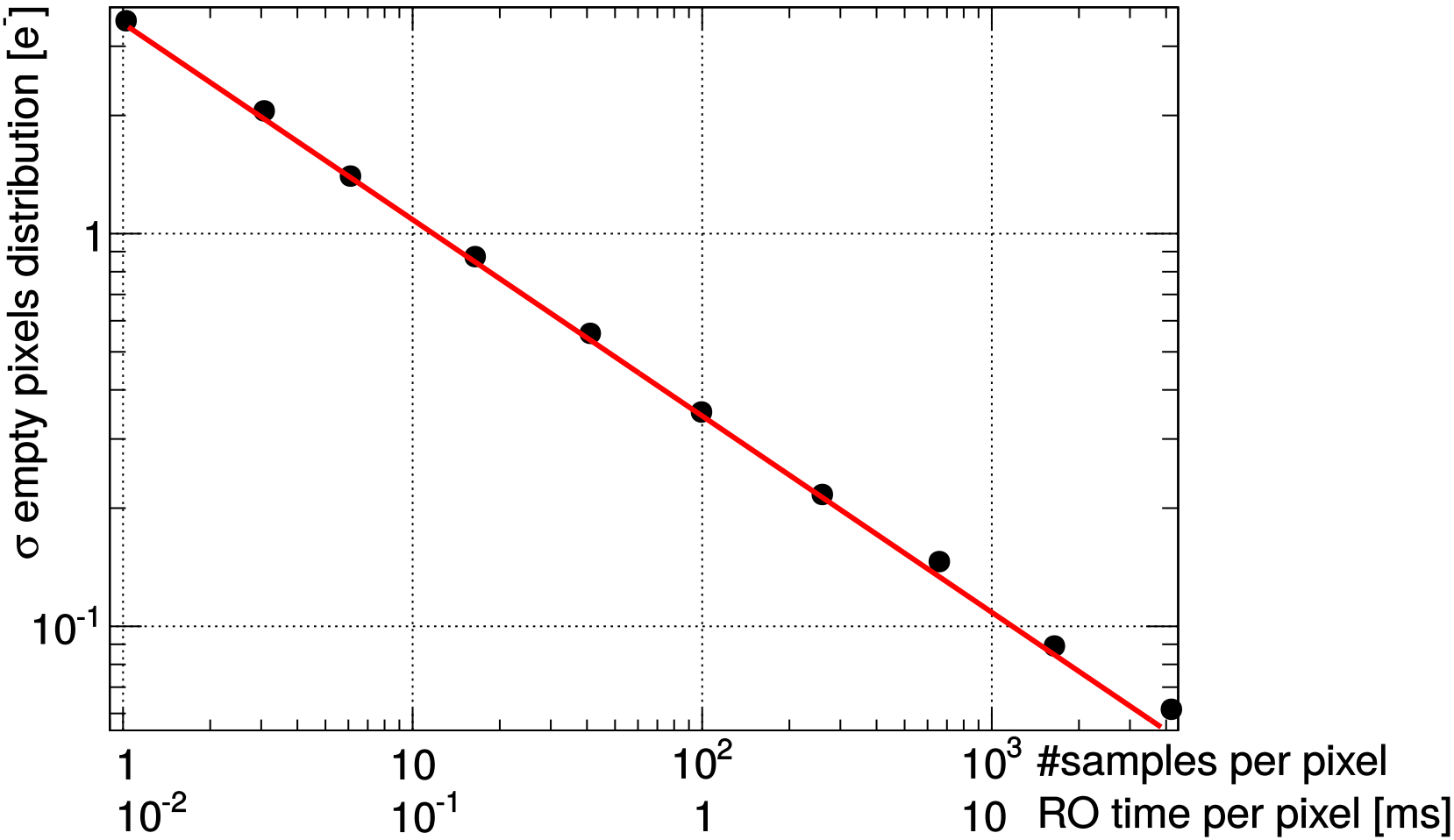


keep counting: ..1575, 1576, 1577..



Noise vs. #samples - $1/\sqrt{N}$



Skipper CCD: Operation mode

- Counting electrons $\Rightarrow$ **noise has zero impact**
- It can take about 1h to readout a 4kx4k sensor
- **Dark Current is the limiting factor**

It's better to readout continuously to minimize the impact of the DC

	Number of DC events (100 g y)	
Thr /e	**DC = 1×10^{-3} e pix^{-1}day^{-1}**	**DC = 10^{-7} e pix^{-1}day^{-1}**
1	1×10^{8}	1×10^{4}
2	2×10^{4}	2×10^{-5}
3	3×10^{-2}	3×10^{-14}

Measured upper limit for the DC in CCDs is $\mathbf{1 \times 10^{-3}}$ **e pix^{-1}day^{-1}**.
Could be orders of magnitude lower. Theoretical prediction is $\mathbf{O(10^{-7})}$.

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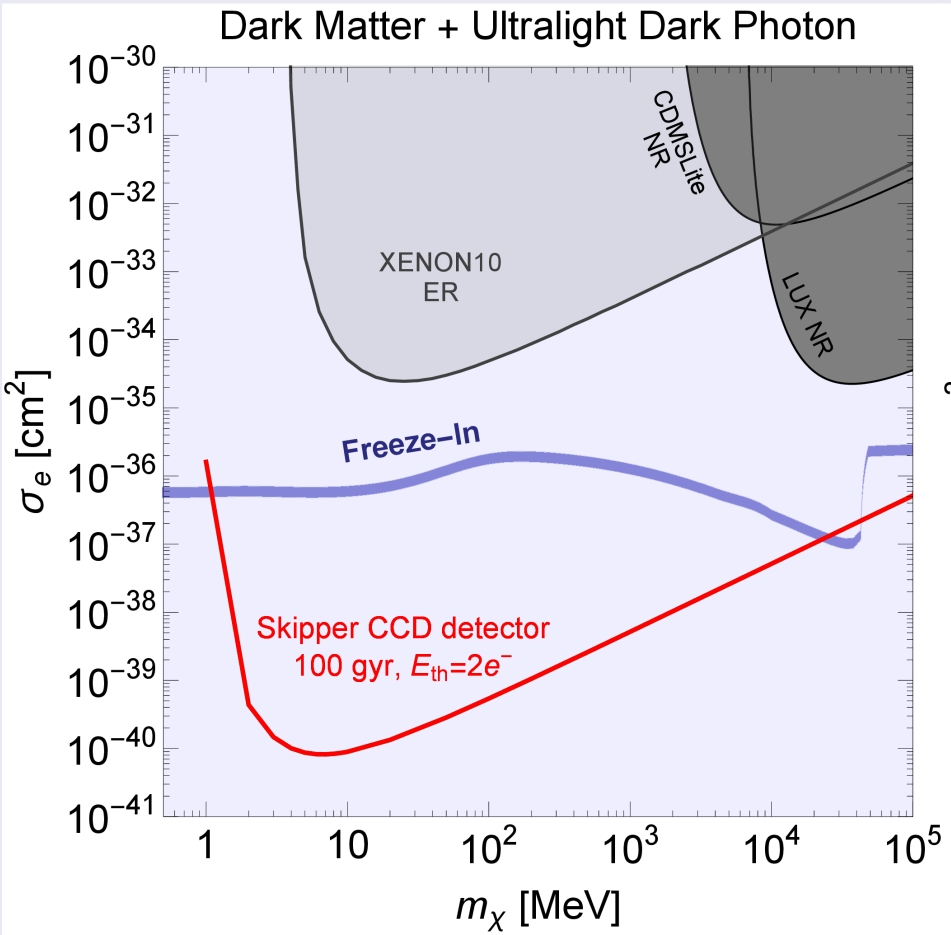
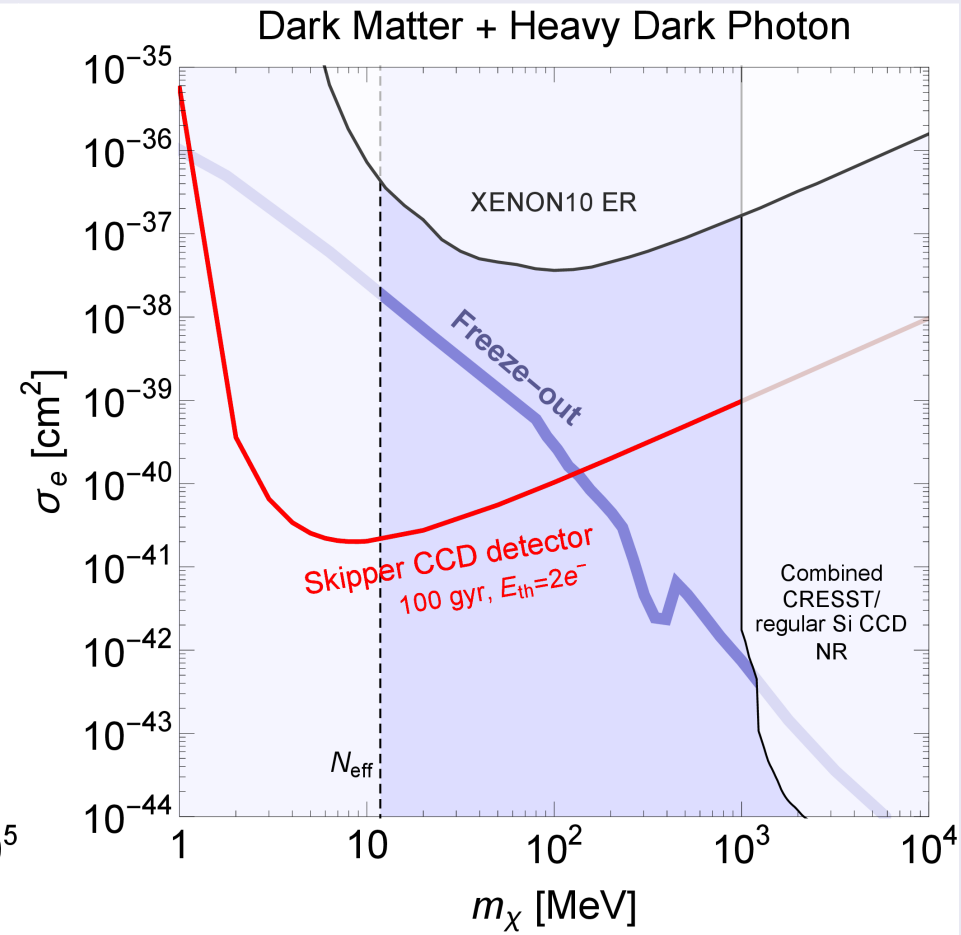
Skipper CCD - electron recoil reach

Electron recoil sensitivity computed by LDRD collaborators:
Rouven Essig, Jeremy Mardon, Tomer Volansky, Tien-Tien Yu.





From yesterday's Agency-Perspective talks

[..] HEP is interested in identifying new, small project(s), for dark matter searches in areas of parameter space (i.e. mass ranges or types of particles) not currently being explored.

New Opportunities in DM Searches (1)

- The search for dark matter (DM) was a high science priority in the 2014 P5 report. P5 also had a recommendation about maintaining a diversity of project scales in the program (i.e. ensuring we have small projects too).
- It is important to cover all relevant phase space to the extent feasible. Currently, the majority of the current support and activity for dark matter search is aimed at WIMP and axion searches and is supported in the Cosmic Frontier. Some projects use accelerator beams to search for particle which connects SM particles to dark sector, and are supported in the Intensity Frontier. LHC and other data are also used to search for DM candidates. There are also considerable theoretical studies of dark matter.
- To respond to the P5 recommendations above, HEP is interested in identifying new, small project(s) for dark matter searches in areas of parameter space (i.e. mass ranges or types of particles) not currently being explored.
- In order to move forward and to understand the possibilities, HEP needs input from the community and is asking the community to organize a workshop in the March/April 2017 timeframe. The workshop should examine the next step(s) for experimentation to explore dark matter, including in unexplored areas of parameter space. It is expected that the workshop will result in a written white-paper report.

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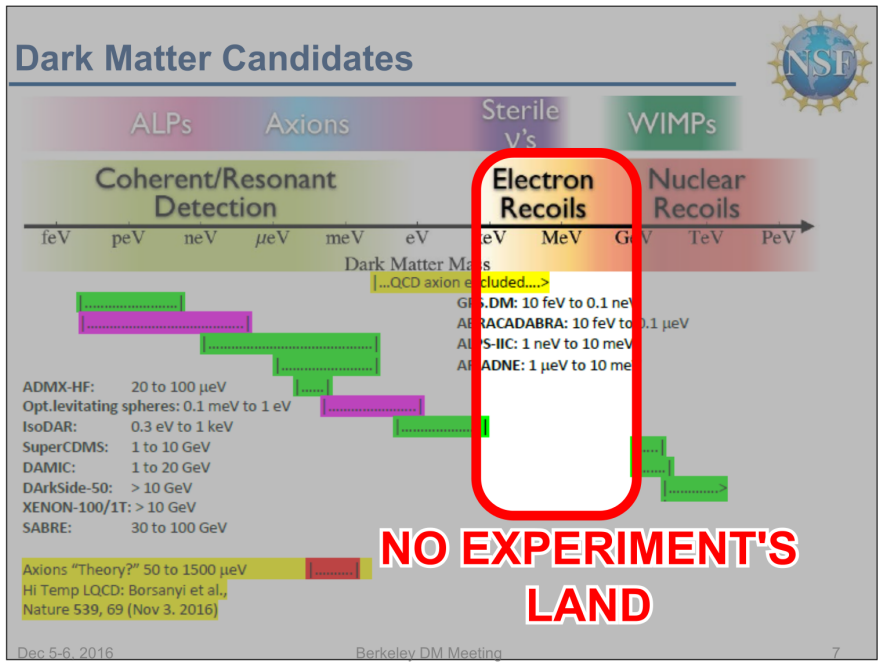
3rd Dark Matter Berkeley Workshop 16



Dec 5-6, 2016 Berkeley DM Meeting 7

SENSEI is the ultimate silicon ionization detector
Dream sensor for electron recoil channel

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SENSEI and Skipper-CCD detectors prospects

SENSEI is the ultimate silicon ionization detector
Unmatched performance for electron recoil channels

- Probe DM masses at the MeV scale through electron recoil.
- Probe axion and hidden-photon DM with masses down to 1 eV.
- Probe DM masses as low as 0.1 GeV through nuclear recoil.
- Push boundaries of coherent ν-nucleus interaction experiments.

Participants

- **Fermilab:** Javier Tiffenberg, Yann Guardincerri, Miguel Sofo Haro
- **LBNL:** Steve Holland, Christopher Bebek
- **Stony Brook:** Rouven Essig
- **Tel Aviv University:** Tomer Volansky
- **CERN:** Tien-Tien Yu
- **Stanford University*:** Jeremy Mardon

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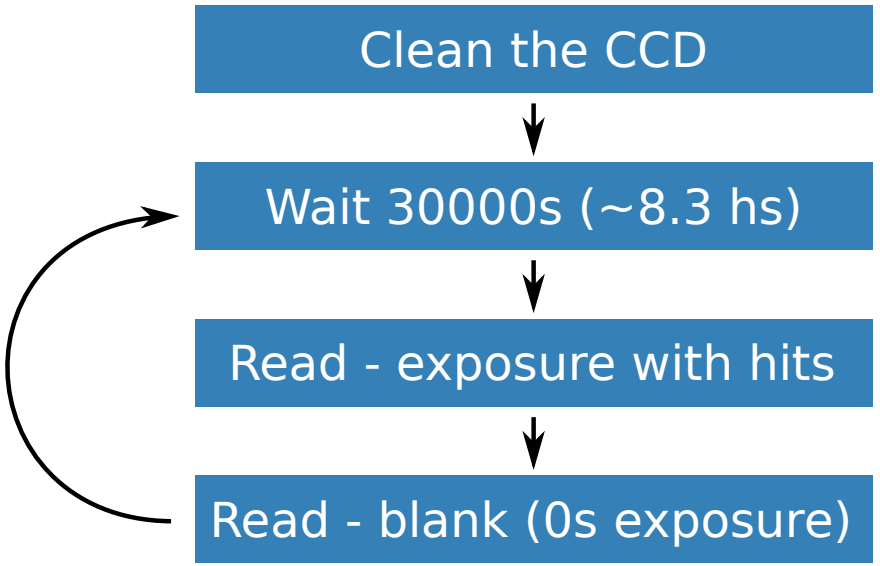
BACK UP SLIDES

CCD: readout - typical operation for DM searches



We take long exposures to minimize the number of readouts. The exposure is eventually limited by the dark current.

The blank images provide an excelent measurement of the background produced by readout

- The number of **real** events (produced by particles) scales with the total exposure time.
- The number of **fake** events (product of readout noise) scale with the number of readings (images taken).

It is better to read as few times as possible.

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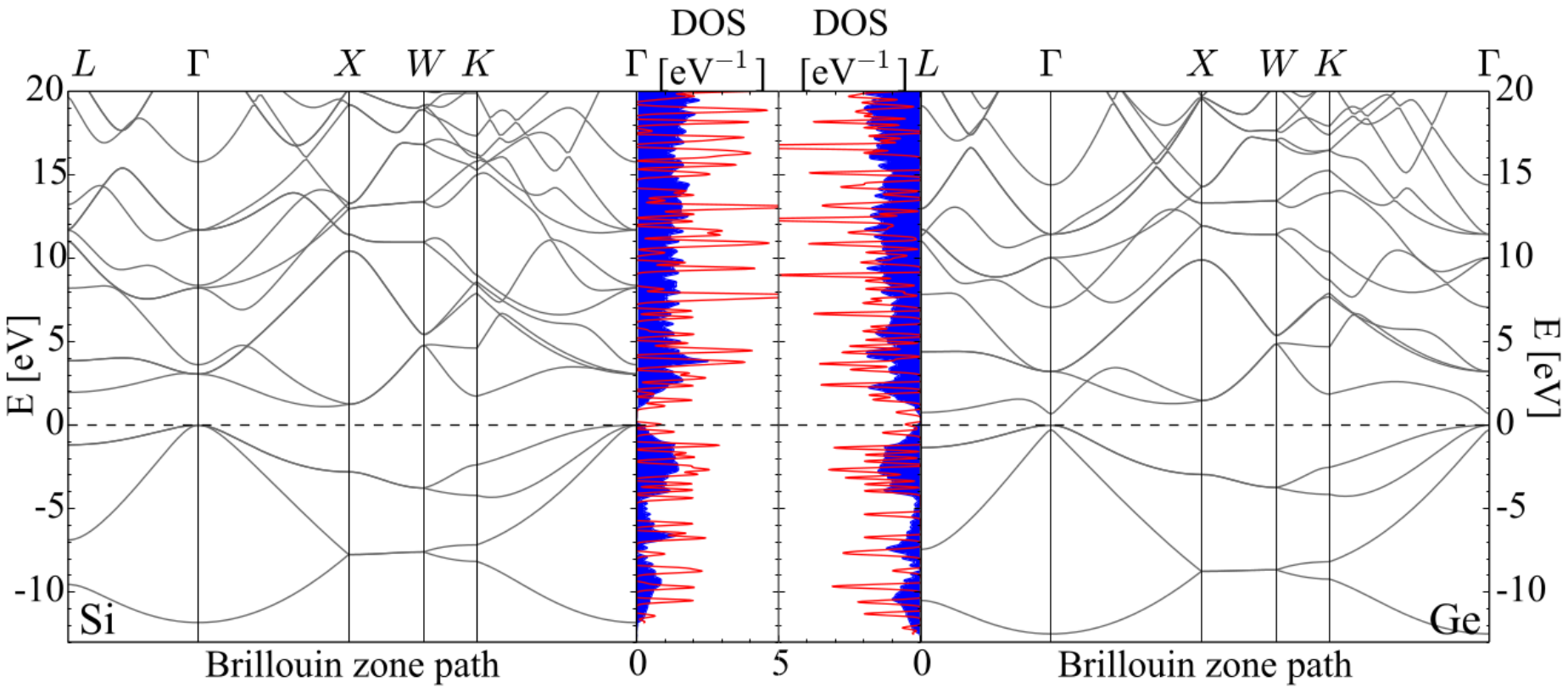
Electron density-of-states (1509.1598)



Whats next: Installation @MINOS & low radiation package